Overview of ISRU Activities at KSC, FIT, and UT-PR

Presented by

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Acknowledgement

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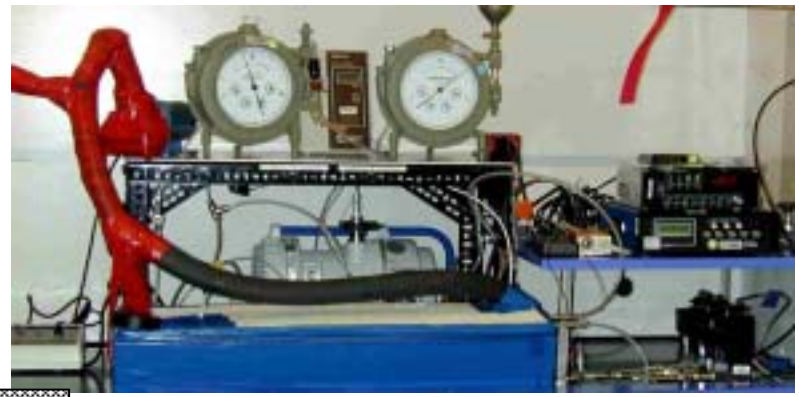
Current Projects At KSC

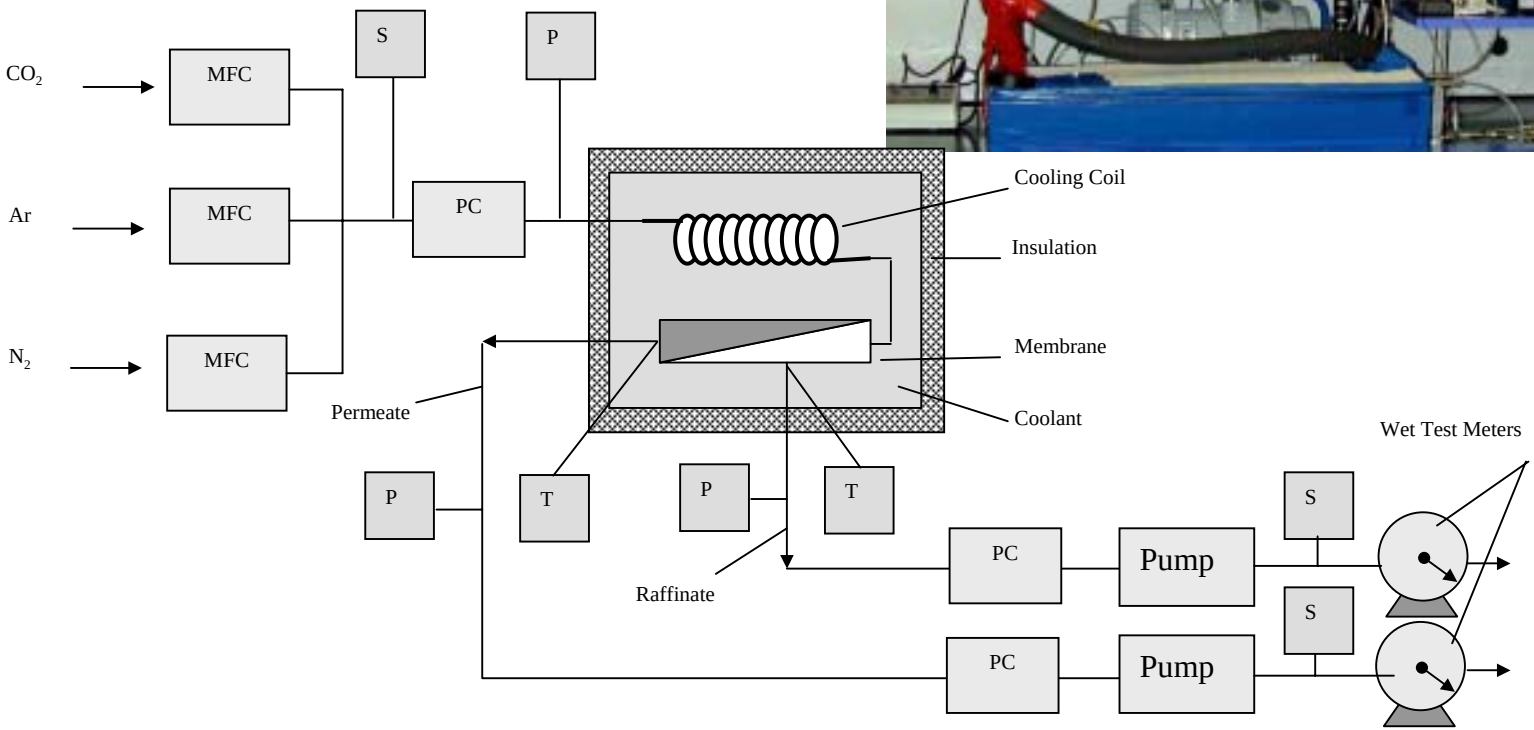
- Gas Separation Processes
  - Low Temperature Membranes
  - Immobilized Liquid Membranes
  - Microencapsulated Liquid Membranes
- Oxygen Production Technologies
  - RWGS
  - Ionic Liquids
  - Molten Salts

Gases Separation Processes

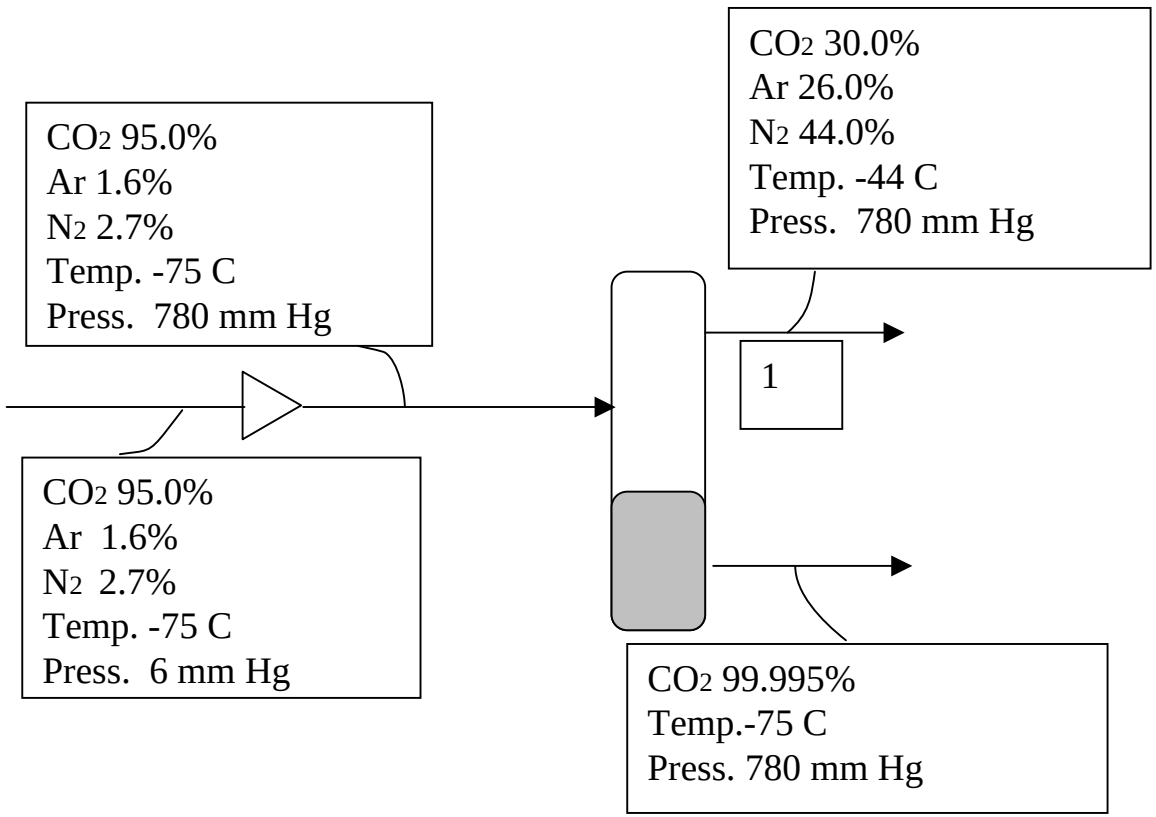
- Separation Methods
  - Hollow-Fiber Membranes
  - Immobilized Liquid Membranes
  - High temperature Membranes (300 to 500 C)
  - Microencapsulated Liquid Membranes
- Applications
  - Buffer Gases for Mars
  - Water Removal from RWGS Process
  - CO_2 Removal for EVA and Spacecraft Applications
  - Regenerative Live Support
- Technical Challenges

Low-Temperature Membrane Test Bed

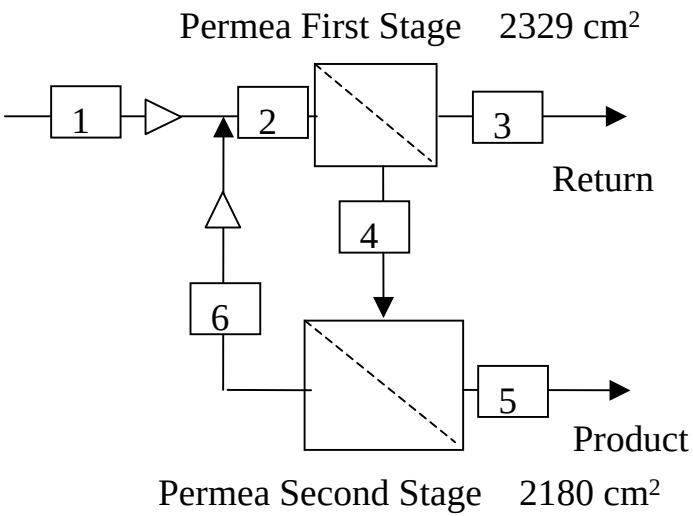




Capture Design for Buffer Gas at - 44° C

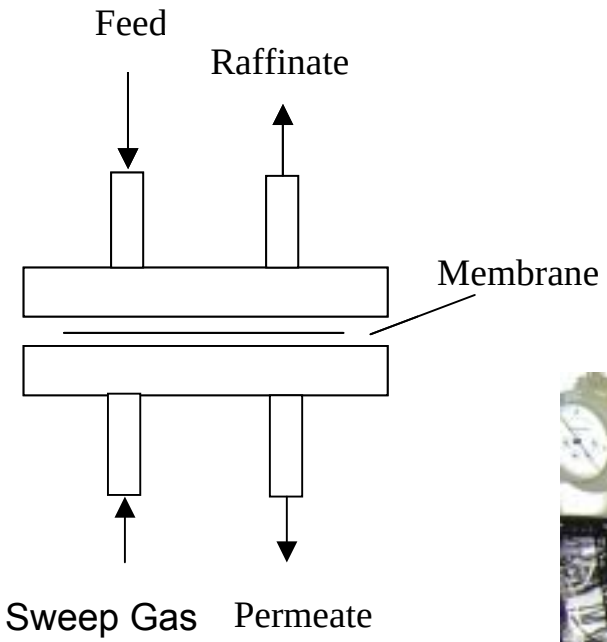


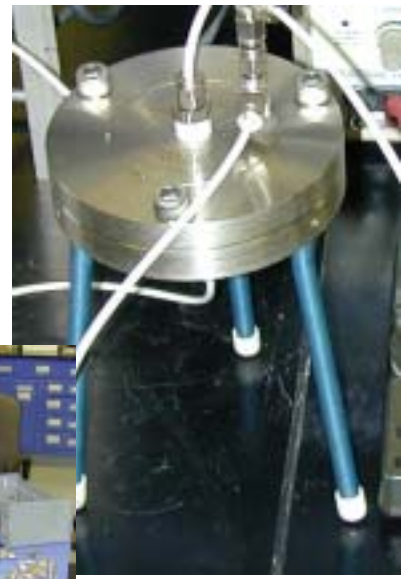
Membrane System Design for Buffer Gas at - 44° C



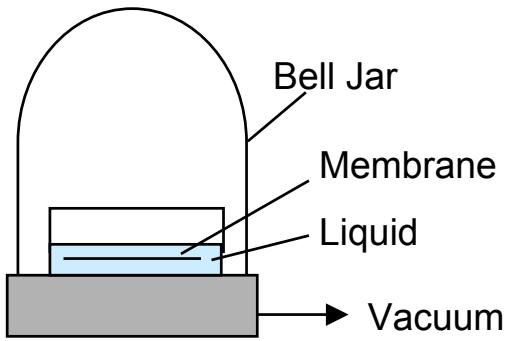
Stream	1	2	3	4	5	6
% CO_2	30	27.62	56.53	8.06	0.06	20.04
% Ar	26	26.9	15.84	34.37	37.72	29.37
% N_2	44	45.48	27.61	57.56	62.22	50.59
Liter/hr	12.77	16.78	6.77	10.01	6	4.01
mm Hg	780	780	6	780	780	6

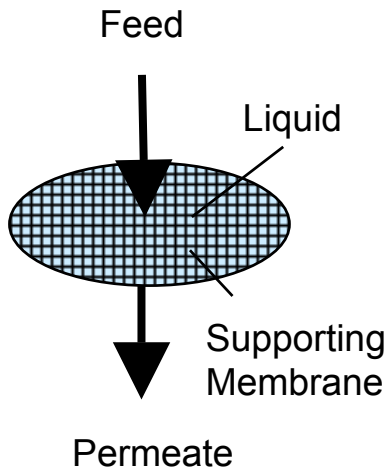
Sample Cell for Membrane Sheet

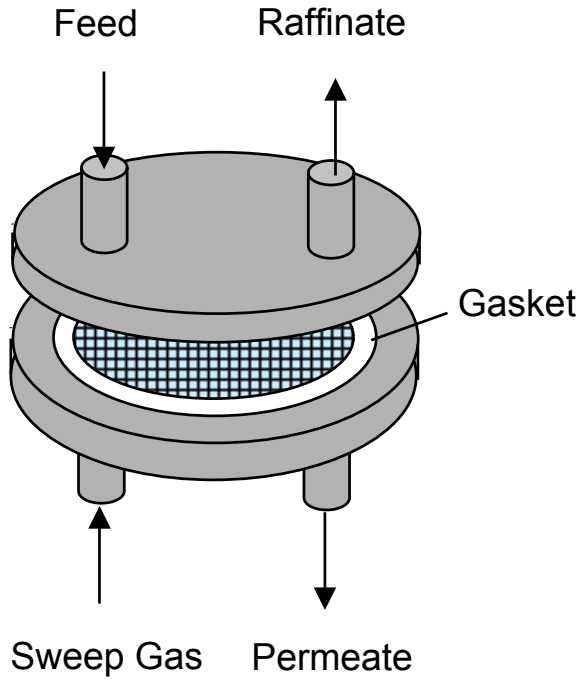




Immobilized Liquid Membranes







Preparation Structure Sample Cell

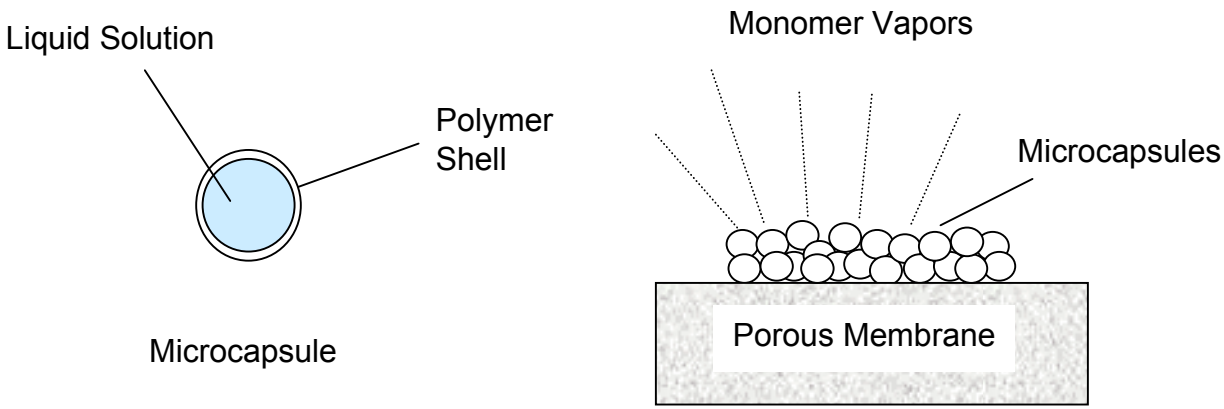
Immobilized liquid membrane preparation, structure, and sample cell

Ionic Liquids

- What are they?
  - Low melting ionic salts. By using large anions and cations, a low temperature melt with conductivity similar to molten salts can be obtained.
  - Examples include pyridinium and imidizolium cations with anions such as PF_6^-, BF_4^-, and many others.

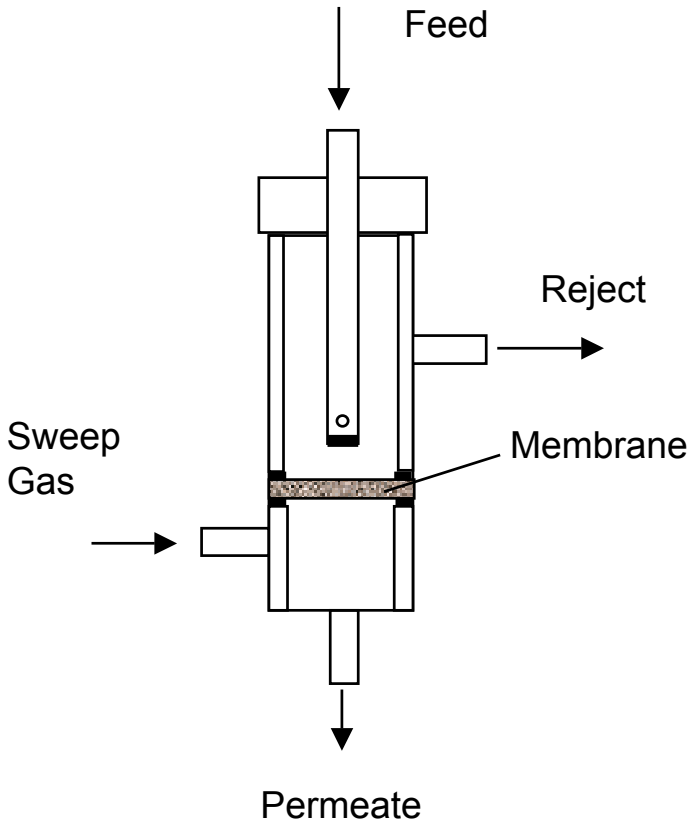
- Desirable Properties
  - Low temperature (177 – 573K).
  - High conductivity (low I*R losses).
  - Wide electrochemical window.
  - Non-volatile.
  - Miscible with or high solubility for CO_2.

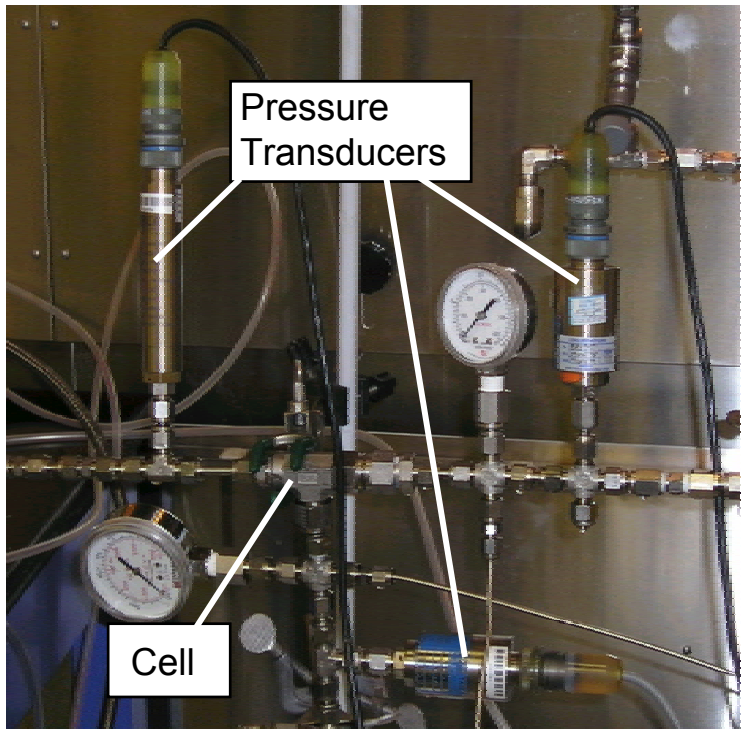
Microencapsulated Liquid Membrane



A microcapsule, group of microcapsules on a porous membrane, and vapors of a monomer that permeates the capsules

Ceramic Membrane Cell

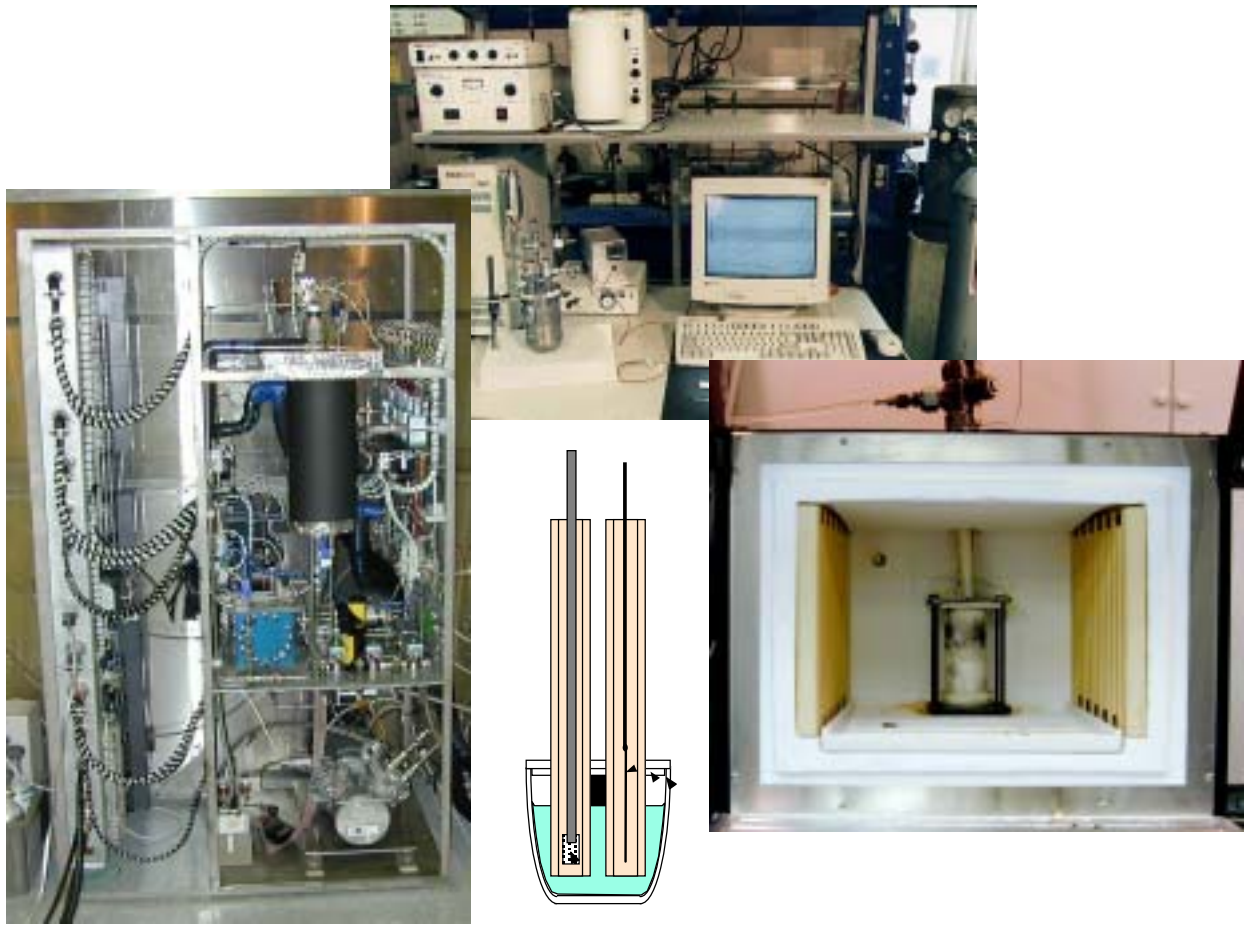




Complex ceramic membranes for hydrogen Separations

Oxygen Production Technologies

- RWGS
- Ionic Liquids
- Molten Salts



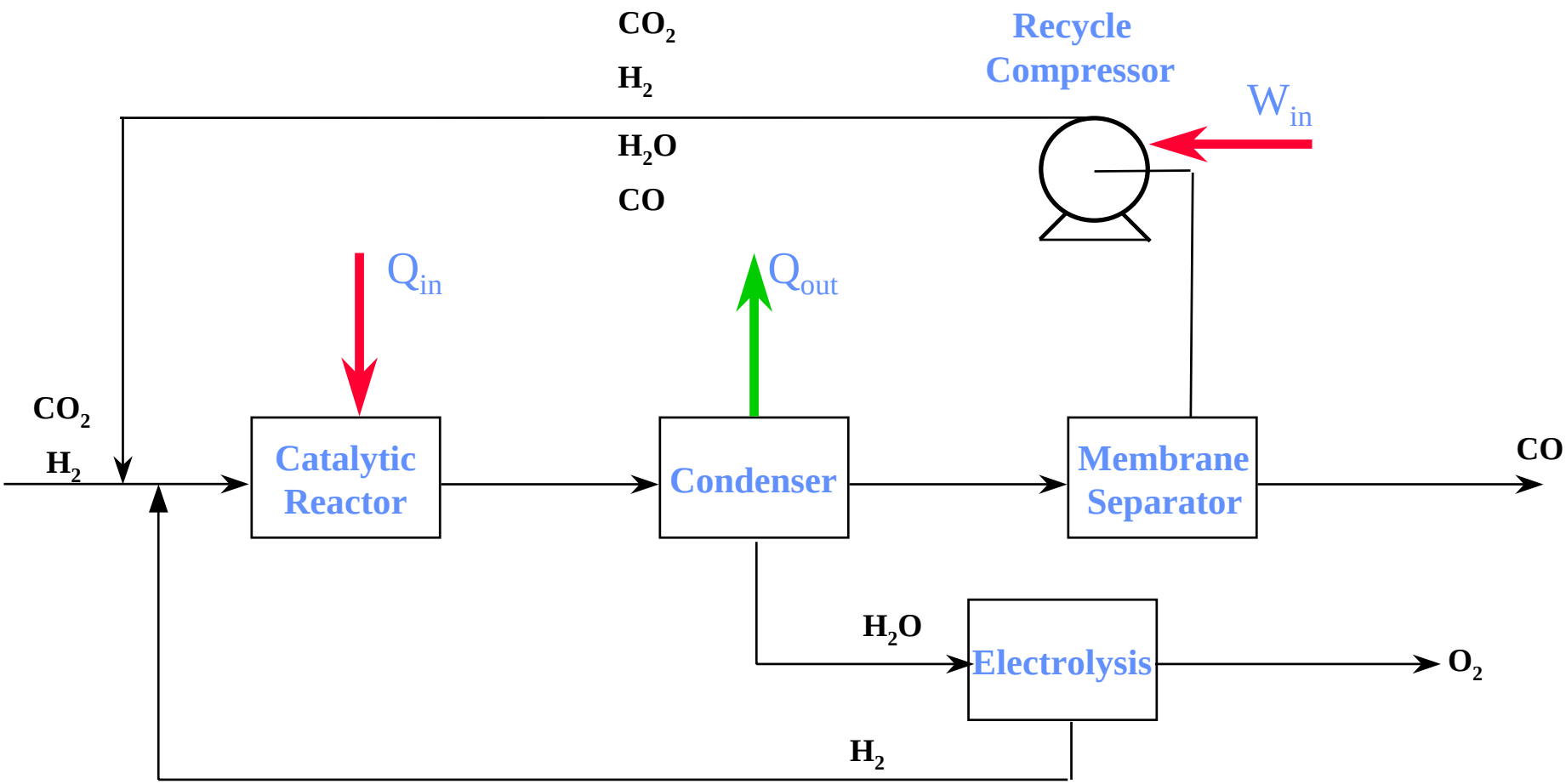
RWGS Cyclic Processes with Water Electrolysis

- Reverse Water Gas Shift Reaction (RWGS)
- Desiccant Electrolysis and RWGS
- Carbon Monoxide Removal

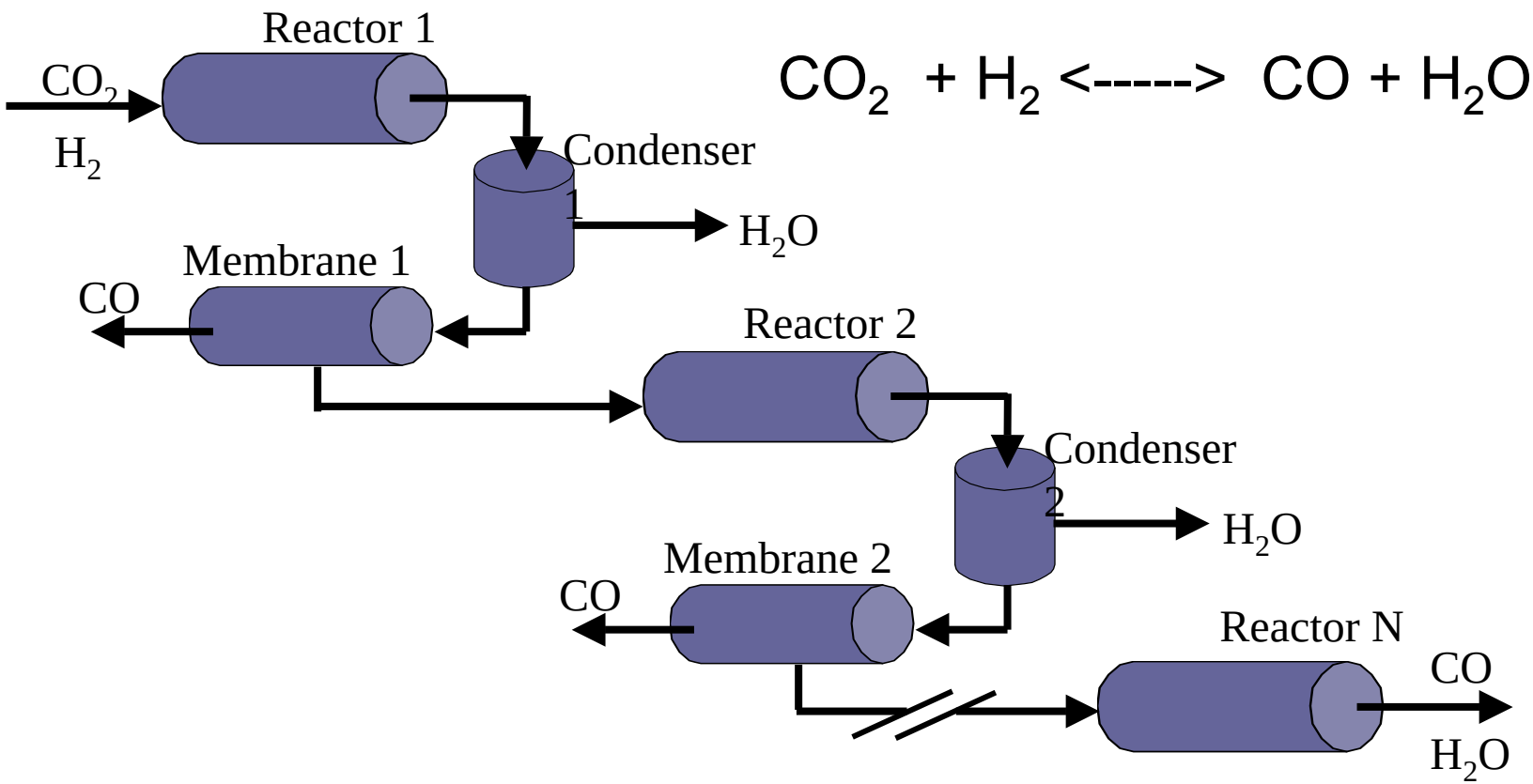
$$CO_2 + H_2 \longrightarrow CO + H_2O$$

$$H_2O \longrightarrow H_2 + \tfrac{1}{2} O_2$$

RWGS Process Flow Diagram



Cascade RWGS Reactor



Base Case for Staged Simulations

	Stage1	Stage2	Stage3	Stage4	Stage5	Stage6
Reactor Temperature(C)	400	400	400	400	400	400
Condenser Temperature(C)	5	5	5	5	5	5
Reactor Pressure (psia)	80	64	48	32	20	12
Membrane Delta P (psia)	16	16	16	12	8	8
Permeate Delta P (psia)	0.15	0.21	0.36	0.70	1.31	3.28
Permeate CO_2 Sweep (slpm)	3	3	3	3	3	3
H_2 Reactor Feed (slpm)	4	2.50	1.38	0.60	0.16	0.01
CO Reactor Feed (slpm)	0.000	0.147	0.101	0.053	0.012	0.002
H_2 in Reject (slpm)	0.00006	0.00007	0.00013	0.00358	0.00212	0.00008
CO in Reject (slpm)	1.35638	1.15943	0.83380	0.47623	0.15234	0.01543
Overall H_2 Conversion	37.44	65.28	84.92	95.90	99.50	99.84

Molten Carbonate Electrolysis of CO_2

Anode Reaction

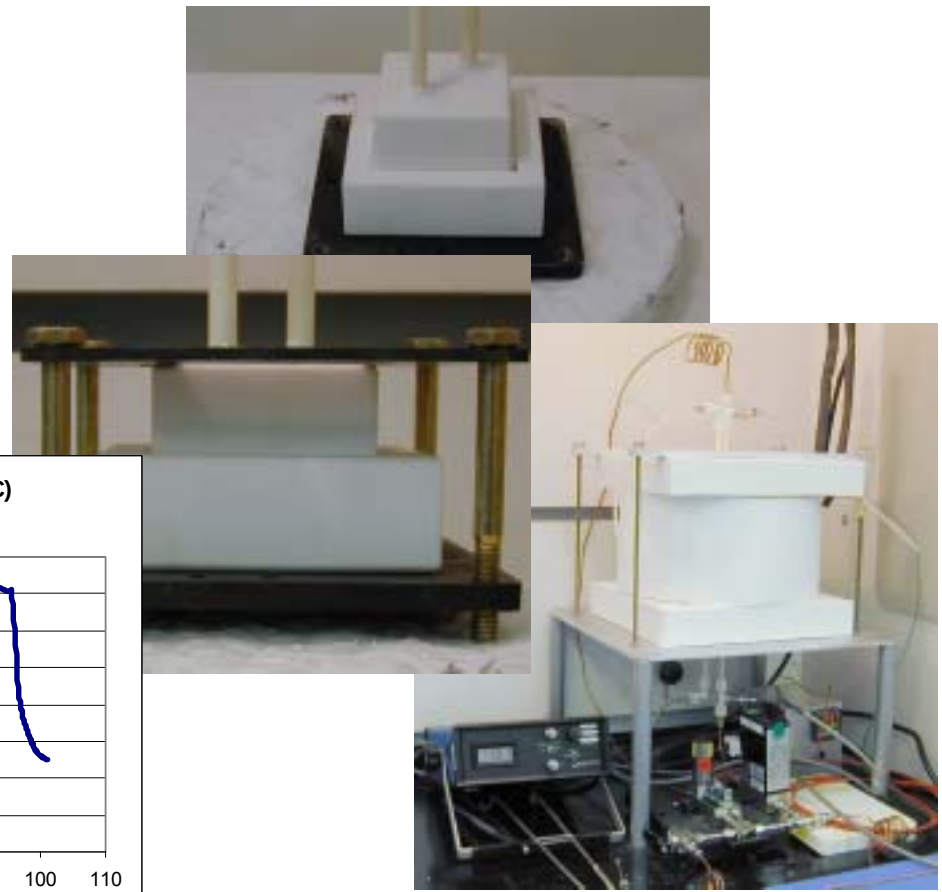
$$2\ CO_3^{-2} \leftrightarrow 2\ CO_2 + O_2 + 4e^-$$

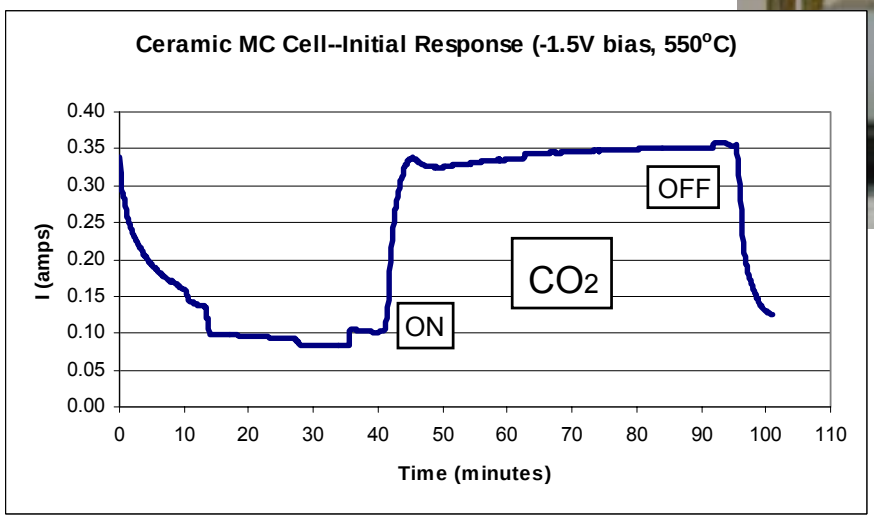
Cathode Reaction

$$4e^- + 4\ CO_2 \leftrightarrow 2\ CO + 2\ CO_3^{-2}$$

Overall Reaction

$$2\ CO_2 \leftrightarrow CO + O_2$$





Ionic Liquids for Carbon Dioxide Electrolysis

- Ionic liquids allow lower processing temperatures
- Organic polymers can be used for gaskets and stainless steel for cells
- Wide electrochemical window
- Good mobility of ionic species
- Low temperature Reactions
  - Anode Reaction

    $CO_2 + 4\ e^- \rightarrow C + 2\ O^{-2}$
  - Cathode Reaction

    $2\ O^{-2} \rightarrow O_2 + 4\ e^-$
  - Overall Reaction

    $CO_2 \rightarrow C + O_2$
  - Carbon removal from ionic liquid